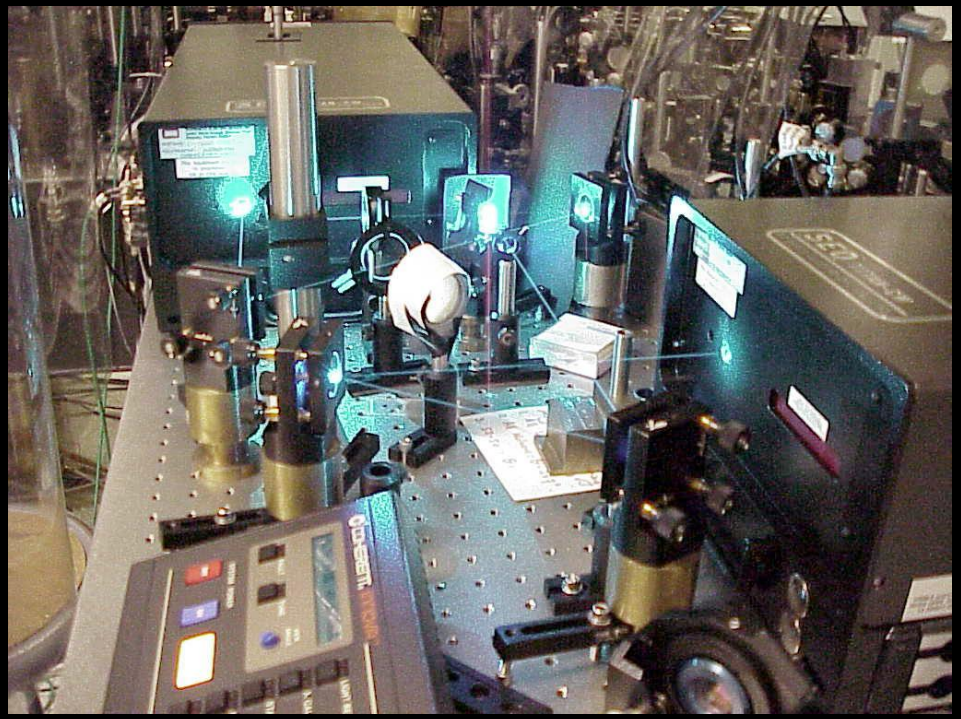
Laser Safety At Cornell



Environmental

Health & Safety

Navigating Through This Presentation

- To move from slide to slide, please use your up and down arrow keys or the PgUp and Pg Dn keys
- The down keys move you forward while the up keys move backward
- The ESC key quits the class
- You must finish the class to receive credit for this training

Purpose of this Program

- To increase awareness in laser safety
  - Low hazard lasers Class 1 to 3a
  - High hazard lasers Class 3b and 4
  - More about laser classes later

Program Outline

- Some Definitions
- Laser Fundamentals
- Laser Classification
- Laser Incidents/Accidents
- Laser Hazards - Eye, Skin, Chemical, and Electrical Hazard
- Safety Guidelines & Control Measures

Some Definitions

- LASER – Light Amplification by Stimulated Emission of Radiation
- MPE – Maximum Permissible Exposure – used for exposure limits to people (typically mW/cm^2), different MPEs for eyes and skin
- Limiting Aperture – max diameter of a circle over which an exposure is measured, taken as 7 mm for the human eye pupil (0.38 cm^2)

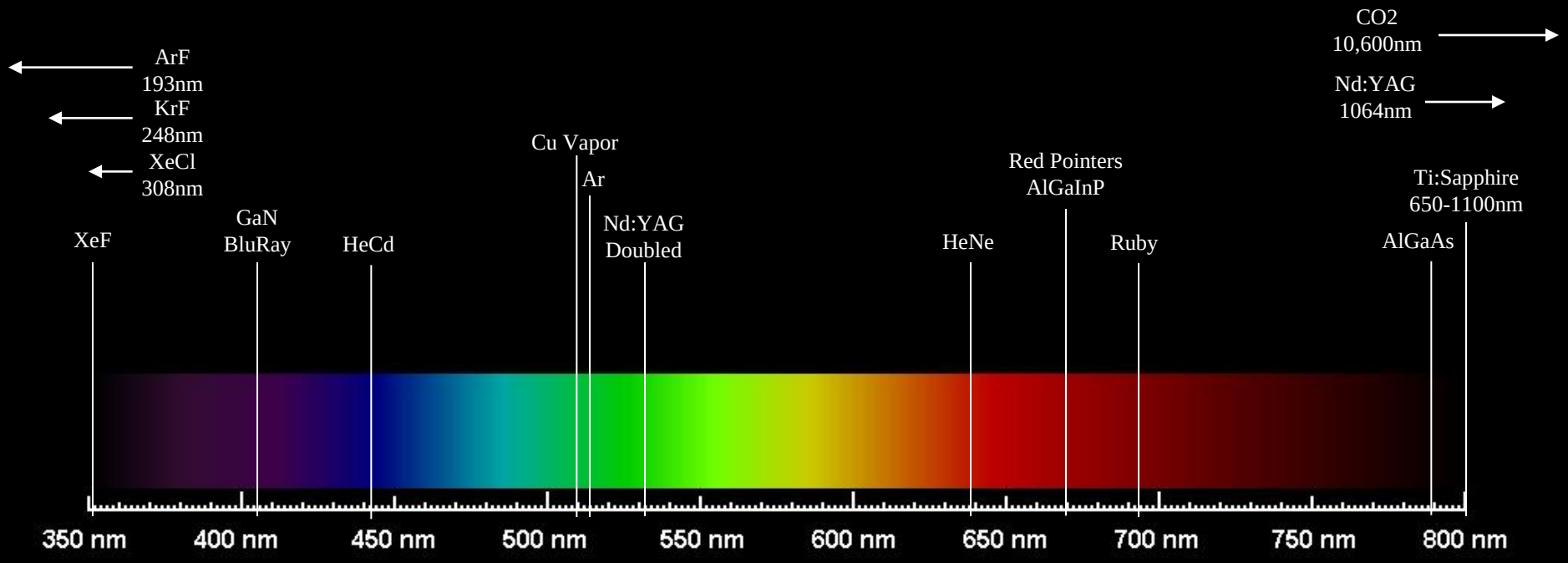
Some Definitions

- Aversion Response – natural reflex response to look away or close your eyes to bright light, about 0.25 sec for humans (blink reflex)
- Controlled Area – any area where access or occupancy is controlled for laser safety purposes, can be an entire room or an area within a barrier or curtain
- Embedded Laser – a laser incorporated into or inside other equipment
- Fail-Safe Interlock – An interlock where the failure of a single component will cause the equipment to go into or remain in a safe state, required by law for laser equipment

Some Definitions

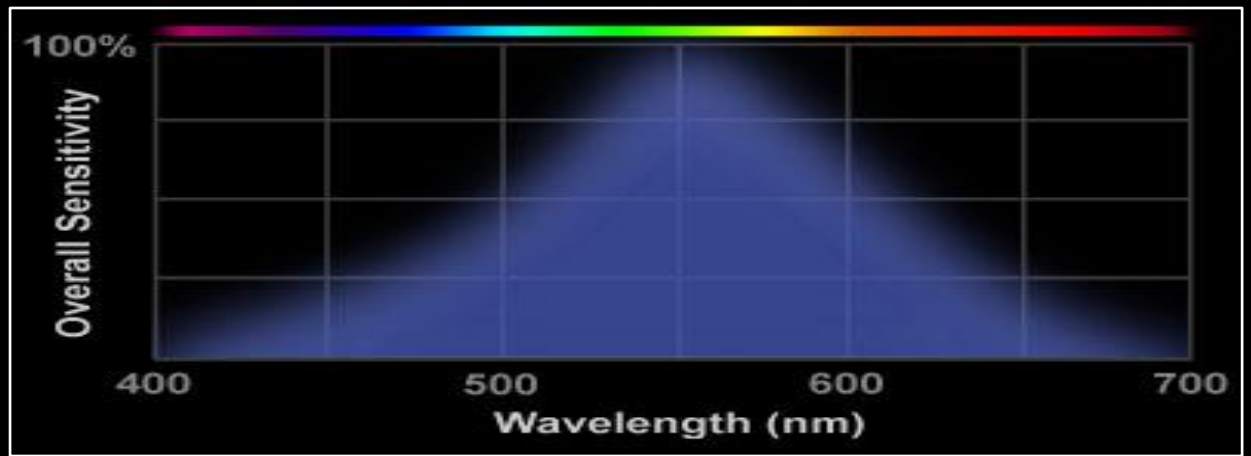
- NHZ - Nominal Hazard Zone – an area where levels of direct, scattered or reflected laser radiation are above the MPE, where ever the beam can possibly travel
- OD - Optical Density – power of 10 reduction of light transmitted through a material – e.g. OD3 = 0.001 fraction of light transmitted thru laser eye protection or other absorber
- UV Light – wavelength shorter than 400 nm
- Visible Light – wavelength 400 – 700 nm
- IR Light – wavelength longer than 700 nm

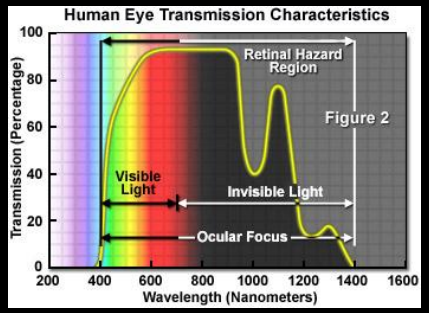
Some Definitions



Visible Continuous Spectrum 2

(Perceived Brightness Partially to Scale)





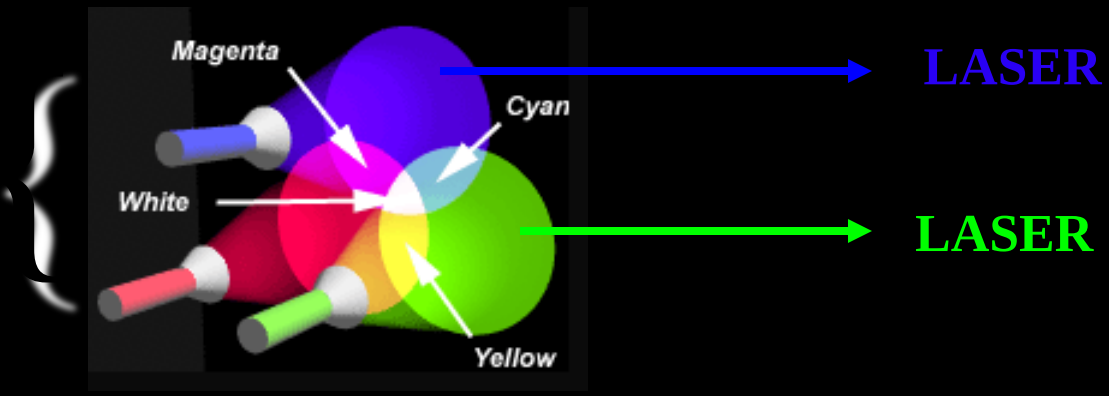
Some Definitions

- In previous slide, the eye can “see” colors shorter than 400 nm and longer than 700 nm BUT you do not see the full intensity
- The bottom graph shows that the eye’s sensitivity drops off rapidly when color moves away from the yellow-green (about 550 nm)
- This picture shows two 5 milliwatt laser pointers, the camera has equal sensitivity across all colors so the spots look equally bright in the picture. In reality the green spot looks much brighter to the eye than the red spot.

Laser Fundamentals

- Characteristics of Laser Light
  - Monochromatic – every photon is the same wavelength, laser beams are single pure color

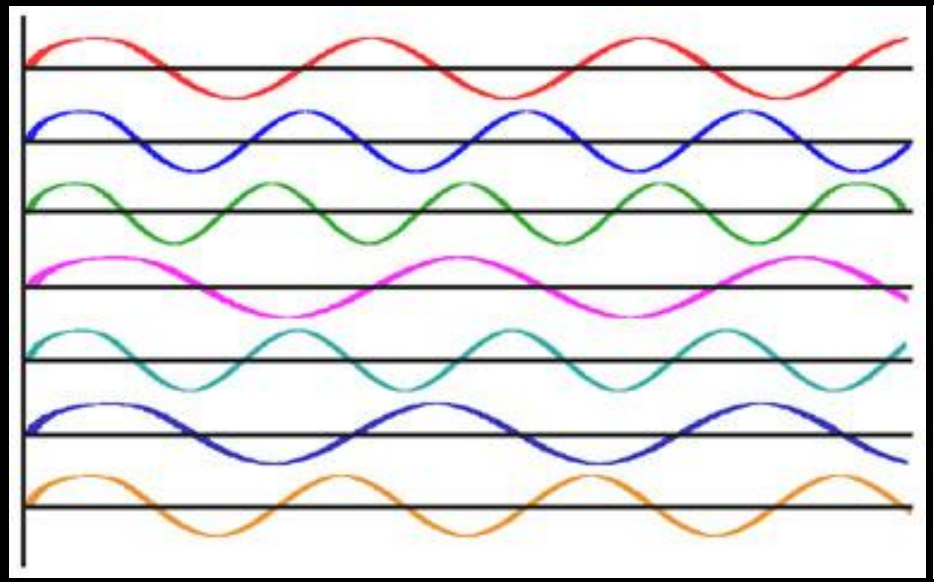
Normal White Light



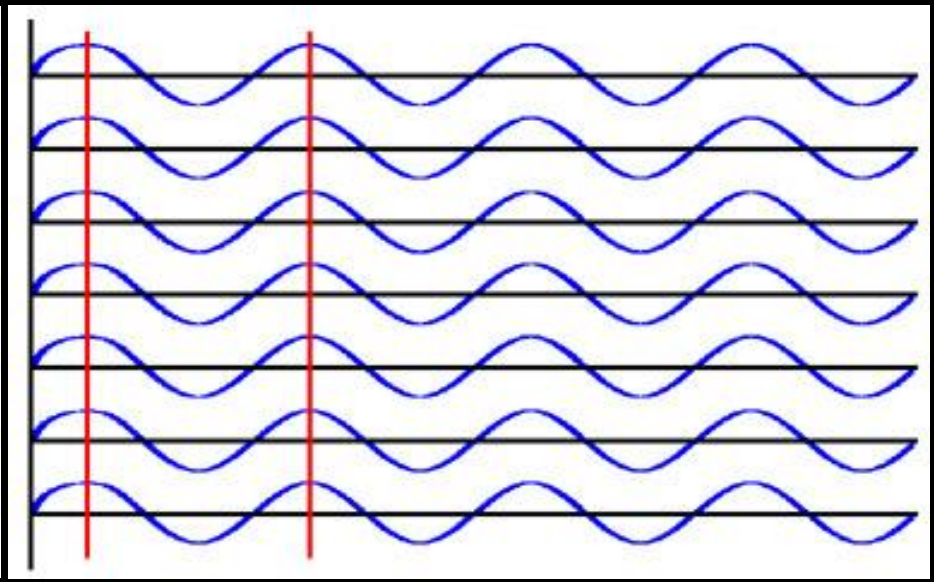
Laser Fundamentals

- Characteristics of Laser Light
  - Coherent – all waves move in step, energy adds together, very high intensity

Normal



Laser

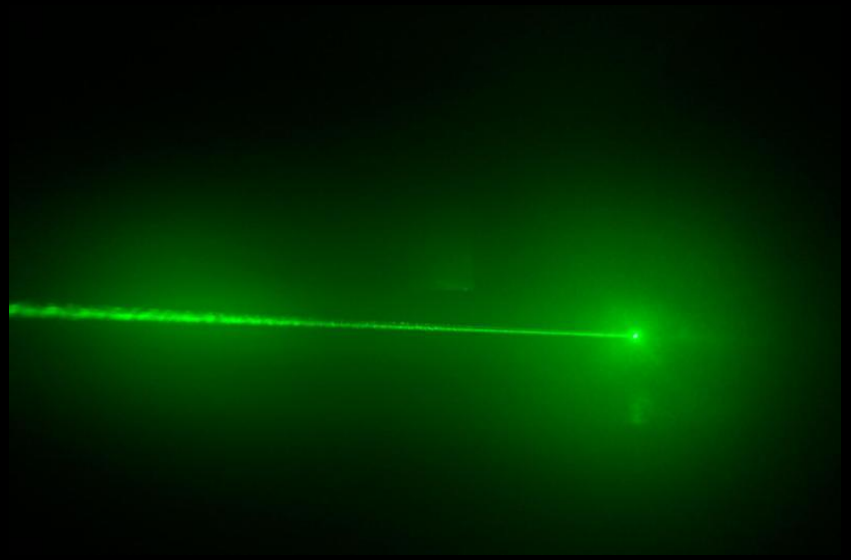


Laser Fundamentals

- Characteristics of Laser Light
  - Directional – narrow beam in a specific direction, small beam divergence (beam spread)

Normal

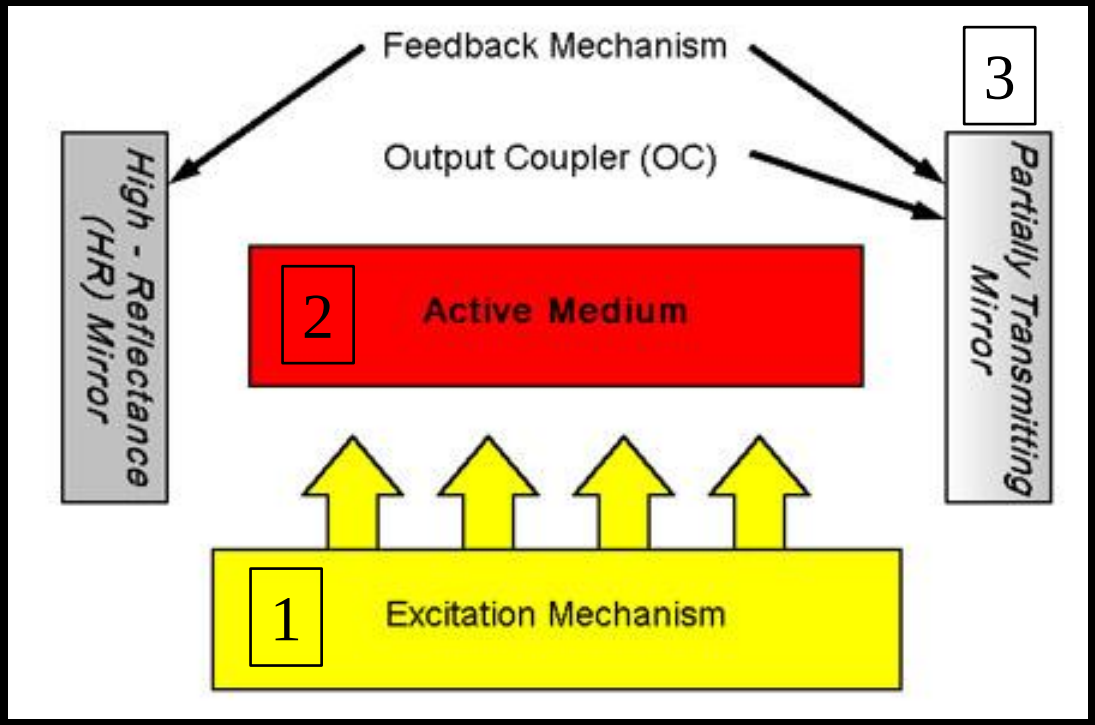
Laser



What Is a Laser?

- How Do Lasers Work?
  - All lasers have the same 3 basic components

1. Energy Source – usually high voltage
2. Active Media – solid, liquid, gas
3. Reflective Surfaces Create Resonate Cavity – beam emitted thru partially reflective mirror



What Is a Laser?

- How Do Lasers Work?
  - Charles Townes, co-inventor of the maser, explains how lasers work

Click video to play

40s

Laser Classifications

Commercial lasers manufactured after August 1, 1976 are classified and labeled by the manufacturer.

Home-built or custom lasers ***MUST*** be classified as part of the safety review - Contact EH&S.

Knowing the laser class can tell you a lot about the hazards and the control measures needed

Laser Classifications

- In US, six laser classes – 1, 2, 2a, 3a, 3b, 4
  - Class number groups lasers with similar hazards
  - Based on power, wavelength and pulse duration
  - Class 1 = no hazard
  - Class 4 = most hazardous
- New class designations for the future

Laser Classifications

Class 1 - Exempt lasers or laser systems that cannot, under normal operation conditions, produce a hazard – must be below MPE

- Visible beams MPE is < 0.4 mW, UV and IR much lower limit
- Usually higher class lasers embedded inside equipment
- Requires protective housing, interlocks, labeling

Example - Compact disk or DVD player

THIS PRODUCT COMPLIES WITH DHHS RULES 21 CF
SUBCHAPTER J APPLICABLE AT DATE OF MANUFACTURE.
CAUTION - INVISIBLE LASER RADIATION WHEN OPEN AN
INTERLOCKS DEFEATED. AVOID EXPOSURE TO BEAM.
CLASS 1
LASER PRODUCT
Manufactured JULY 1999

Laser Classifications

Class 2 - Do not normally present a hazard, but may if viewed directly for extended periods of time

- Visible wavelengths only, > MPE but < 1 mW
- Invisible lasers cannot be Class 2, only visible
- Above MPE for direct beam eye exposure longer than 0.25 sec (aversion or blink reflex protects the eye)

Example - Most alignment lasers are Class 2

- Class 2a is special case of Class 2
  - Above MPE for viewing > 1000 sec

Laser Classifications

Class 3a – Visible wavelengths > 1 mW but < 5 mW
Invisible wavelengths > Class 1 but < 5 * Class 1 AEL

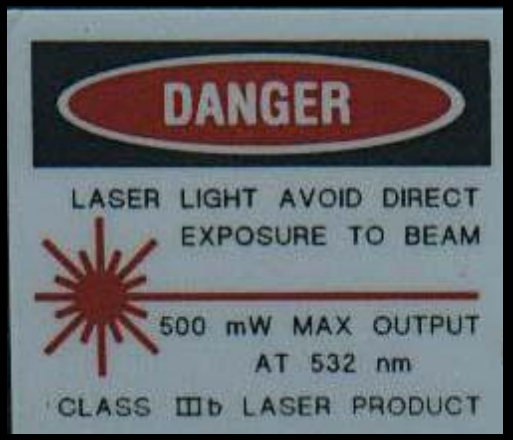
- Hazardous for direct beam eye exposure with optics for less than 0.25 sec (aversion or blink reflex does NOT protect the eye)
- DANGER label

Example - Some laboratory lasers (including normal HeNe up to 5 mW total power), laser pointers, laser levels

Laser Classifications

Class 3b - Visible wavelengths > 5 mW (Class 2) but < 500 mW

- Invisible wavelengths > Class 1 but < 500 mW
- Hazardous for direct beam eye exposure less than 0.25 sec
- Hazardous to skin in upper region of limit, especially UV (sunburn) and IR (heat beams)
- Not a diffuse reflection or fire hazard



Laser Classifications

Class 4 - Visible and invisible wavelengths
> 500 mW

- Definitely hazardous for direct beam eye exposure less than 0.25 sec
- Hazardous to skin
- Is a diffuse reflection and/or fire hazard

DANGER
INVISIBLE LASER RADIATION
AVOID EYE OR SKIN EXPOSURE
TO DIRECT OR SCATTERED RADIATION
EXCIMER LASER
1 J MAX PULSE, 100 MAX PPS at 157-351 nm
CLASS IV LASER PRODUCT

International Laser Classifications

US moving towards international commonality

- Class 1 – eye safe with optical aids
- Class 1M – eye safe except with optical aids
- Class 2 – safe for momentary viewing
- Class 2M - safe for momentary viewing except with optical aids
- Class 3R – replaces Class 3a, marginally unsafe intrabeam viewing
- Class 3b – same as current US requirements
- Class 4 – no changes

- Optical aid includes magnifying glass, microscope, telescope, binoculars, or any optic that collects more light than the eye alone

Laser Standards and Regulations

- Laser safety regulations
  - FDA CDRH 21 CFR 1040 Subchapter J for manufacturers of lasers and laser equipment, product safety standard
- Laser safety standards
  - Standards for the safe use of lasers, for laser users

Laser Safety Regulations

- Food and Drug Administration (FDA)
  - Center for Devices and Radiological Health (CDRH)
  - 21 CFR 1040 Subchapter J
  - Federal law provides standards for product safety
  - Exception – equip you build and operate yourself
  - Performance requirement examples
    - Protective housings
    - Safety interlocks
    - Emission indicators and controls
    - Viewing optics
    - Etc.

Laser Safety Regulations

- FDA CDRH 21 CFR 1040 Subchapter J
  - Labeling requirements
    - Warning logo e.g. CAUTION or DANGER
    - Non-interlocked or defeatable interlocks
    - Invisible beam warnings
  - Documentation requirements
    - Users safety information in user's manual
    - Service safety information in service manual

Laser Safety Regulations

- If you build or modify laser equipment for other users, you may be a laser equipment manufacturer and may be required to follow FDA requirements

- Contact EH&S for assistance

Laser Safety Regulations

- OSHA
  - General duty clause for protecting workers
  - References ANSI Z136 standard
  - STD 01-05-001 Guidelines for Laser Safety and Hazard Assessment

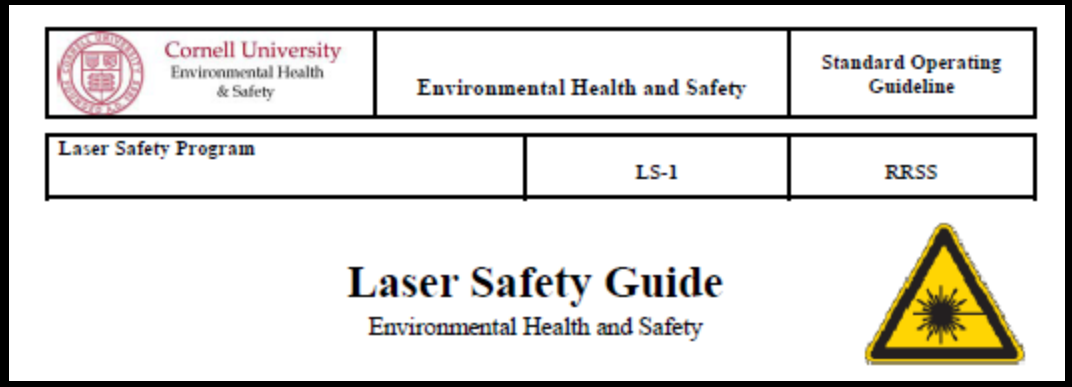
Laser Safety Standards

- American National Standards Institute (ANSI)
  - ANSI are consensus standards
  - ANSI Z136.1-2000 For Safe Use of Lasers
  - Recommends laser MPEs and AELs
  - Often used as basis for regulations
  - Other ANSI Z136.x apply to specific uses
    - Z136.5 for educational institutions
- Cornell will follow ANSI

ANSI
American National Standards Institute

Cornell Laser Safety Manual

- Cornell Laser Safety Manual
  - Available from EH&S web page
  - *www.sp.ehs.cornell.edu* then click the Lab & Research Safety followed by the *Radiation Safety* link



Cornell University Environmental Health & Safety	Environmental Health and Safety	Standard Operating Guideline
Laser Safety Program	LS-1	RRSS

Laser Safety Guide

Environmental Health and Safety

Laser Accidents

- The times when accidents happen
  - During alignment
  - Under stress or pressure
  - When tired
  - Failure to pay attention to work

Top Factors In Laser Accidents

The overall analysis reveals that laser accidents generally fall into one or more of the following major categories:

- Unanticipated eye exposure during alignment.
- Available eye protection is not often used.
- Equipment malfunction causes many unwanted exposures.
- Improper methods of handling high voltage lead to severe shock and even death.
- Protection for non-beam hazards is often lacking.
- Improper restoration of equipment following service frequently causes undesired hazards.
- Incorrect eyewear selection and/or eyewear failure are frequent causes of unwanted exposure.

Most Common Lasers Producing Laser Related Incidents

Laser Type	Percentage
Nd:YAG	29.7
Argon	20.5
CO2	12.8
Dye	9.9
HeNe	7.0
Ruby	6.2
Unspecific	5.5
Do. YAG/Ruby	3.7
Other (HeCd,Cu..)	3.7
Diode	1.1

Occupations of Persons Involved in Incidents

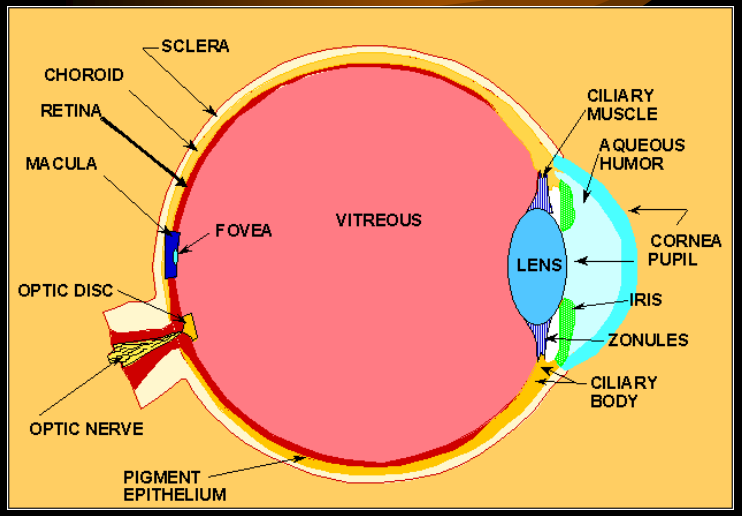
Occupation	Percentage
Technicians	21.3
Scientists	17.6
Patients	12.9
Plant Workers	10.7
Doctor/Nurse	9.2
Students	8.4
Spectators	4.8
Laser Show Operators	4.0
Pilot/Military	3.3
Equipment	3.3
Field Service	2.6
Office Staff	1.8

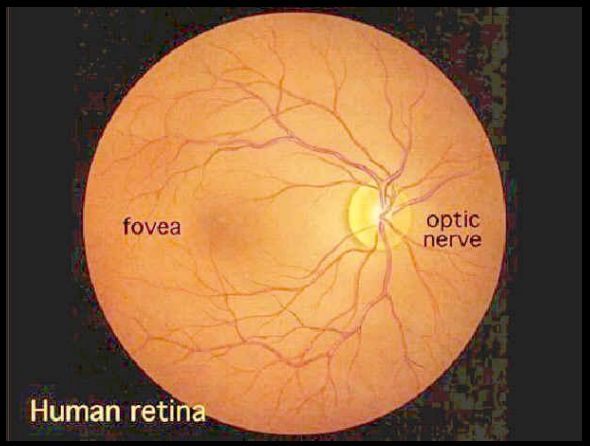
Exposure Incidents

- For actual laser injuries
  1. Contact 911, medical assistance will be sent
  2. EH&S will be alerted automatically
  3. Inform your PI or supervisor immediately
  4. Contact Gannett Health Center (255-5155)
- For near misses and avoided accidents
  - Contact EH&S 255-8200

Laser Hazard - Eyes

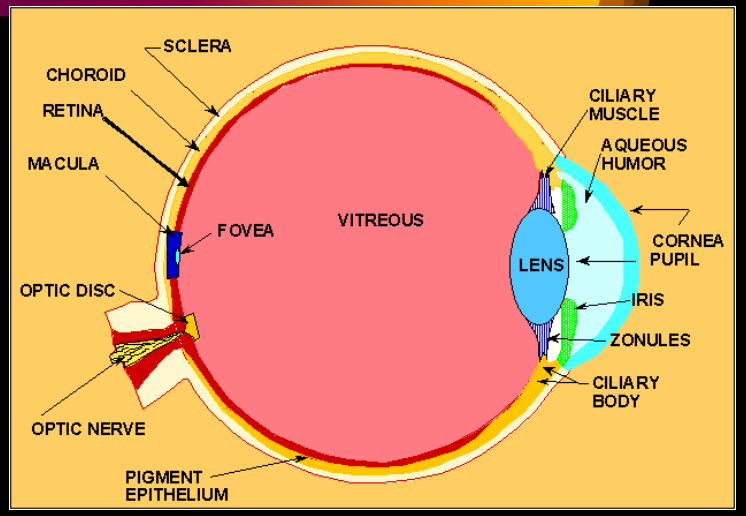
- Eye structures important for lasers
  - Cornea – Interface to the environment, protected by thin tear film, high metabolism, outer cells replaced every 24 – 48 hours
  - Lens – Focuses images on retina, flexible crystalline structure, slow metabolism, not repairable so damage causes cataracts and discoloration

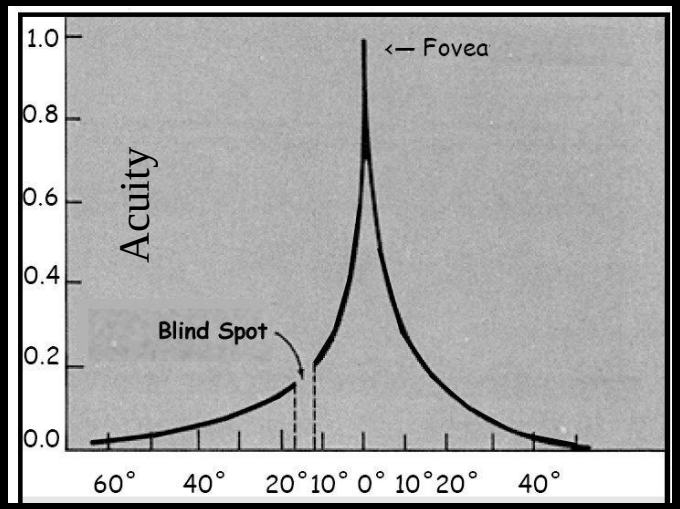




Laser Hazard - Eyes

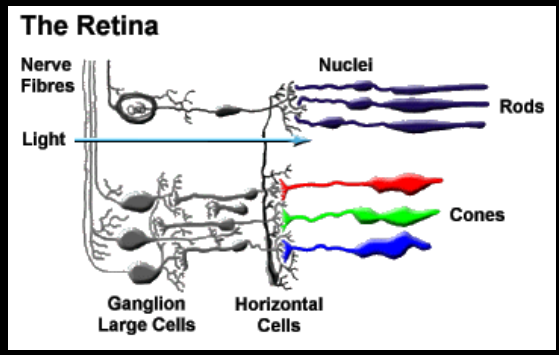
- Eye structures
  - Retina - rods for night and peripheral vision, cones for color and resolution
  - Macula and Fovea – Macula provides central vision while fovea (~0.15 μm wide) has highest concentration of cones for detailed vision e.g. reading or looking directly at an object





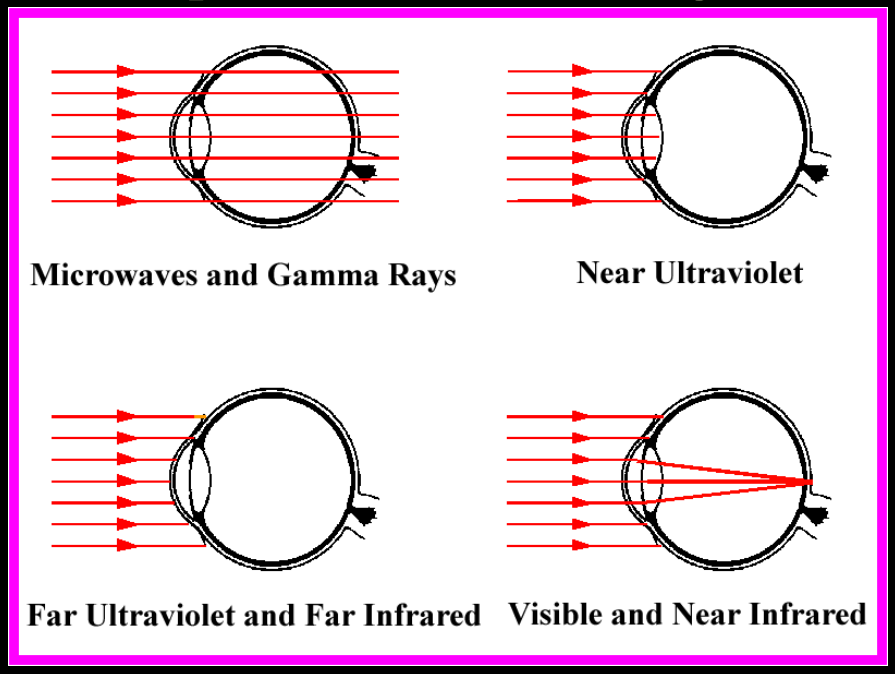
Laser Hazard - Eyes

- Eye structures
  - Cornea – far UV and far IR strongly affect cornea due to water absorption in outer cell layer
  - Lens – mid UV and IR causes damage leading to cataracts (scar tissue in the lens)
  - Macula/fovea – retinal burn destroys sharp vision, unable to render objects sharply, can cause legal blindness

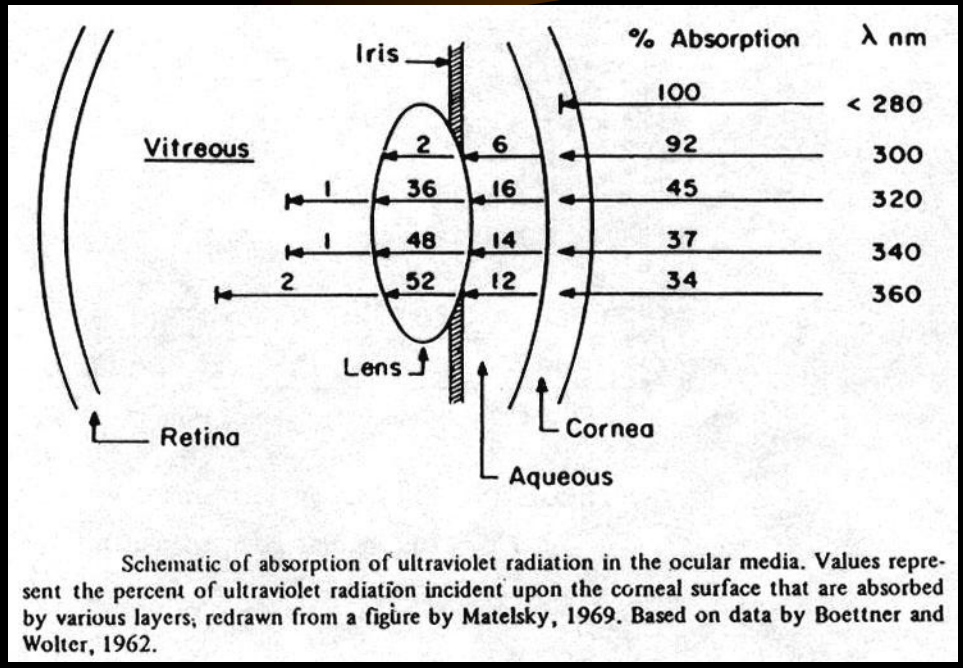


Laser Hazard - Eyes

Exposure vs. Wavelength



Strong UV Absorption in Lens



Schematic of absorption of ultraviolet radiation in the ocular media. Values represent the percent of ultraviolet radiation incident upon the corneal surface that are absorbed by various layers; redrawn from a figure by Matelsky, 1969. Based on data by Boettner and Wolter, 1962.

Laser Hazard Summary - Eyes

- Visible and NIR – thermal damage
  - Lens focusing concentrates light by ~100,000 times, 1 mW/cm^2 into eye becomes 100 W/cm^2 at retina
  - Damage occurs when retinal blood flow can't absorb the extra heat load
  - < 1 mW/cm^2 with blink reflex not likely to cause damage (Class 1 and 2)

Laser Hazard Summary - Eyes

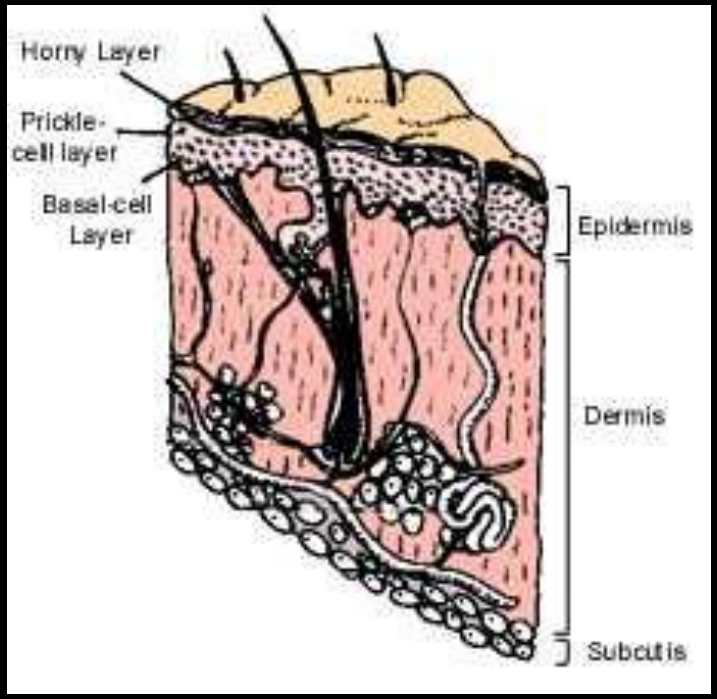
- UV – photochemical damage
  - UVA (315 – 400 nm) lens absorption leading to cataracts
  - UVB (280 – 315 nm) and UVC (< 280 nm) most absorption in cornea and sclera leading to photokeratitis (painful, irritated itchy eyes usually lasts few days)

Laser Hazard Summary - Eyes

- Pulsed lasers
  - Pulses < ~10 μsec can have acoustic shock effects with severe mechanical damage to tissues
  - Rare event but possible

Laser Hazard - Skin

- Skin Structure
  - Stratum Corneum – Outer most layer of dead cells, ~ 8 – 20 μm
  - Epidermis – Outer most layer of living cells, ~ 50 – 150 μm, tanning layer
  - Dermis – Mostly connective tissue, gives elasticity and strength, blood supply and nerves, 1 – 4 mm
  - Subcutaneous – Mostly fatty tissue for insulation and shock absorption over muscle



Laser Hazard Summary - Skin

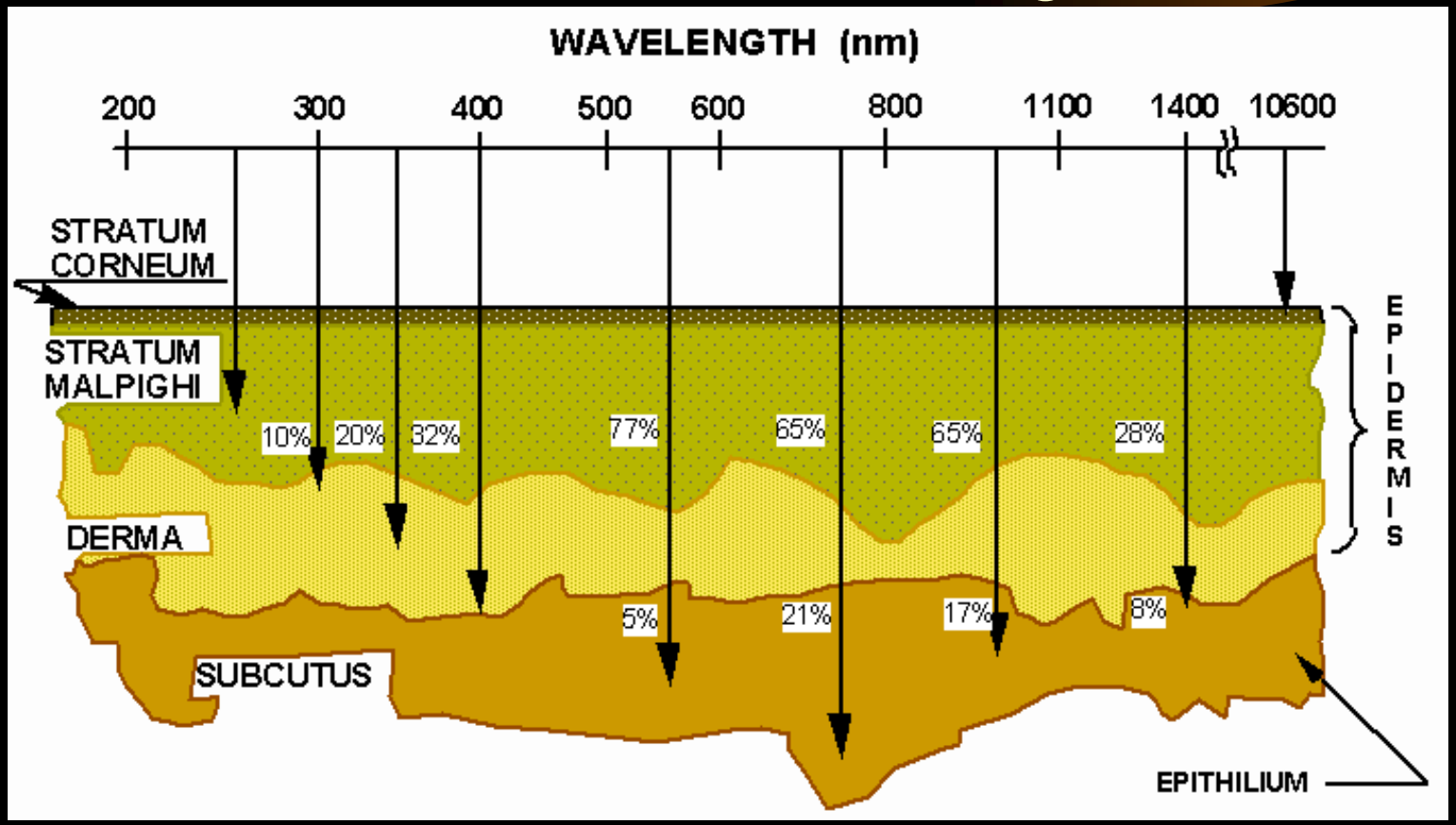
- Visible and IR
  - Skin much more robust compared to the eyes
  - Thermal effects predominate throughout skin depth
  - Thermal damage strongly dependent on exposure duration and area exposed
  - Repairable tissue will heal just like any thermal burn

Laser Hazard Summary - Skin

- UV Range
  - Near UV (UVA 315 – 400 nm)
    - Erythema (sunburn), pigmentation darkening (tanning)
  - UV (UVB 280 – 315 nm)
    - Erythema, possible carcinogenic effects
  - Deep UV (UVC <280 nm)
    - Limited data but possible carcinogenic effects
- UVB most hazardous, surface to epidermis effects
- Effects of erythema (like sunburn) are delayed
- Certain chemicals and prescription drugs can increase skin sensitivity

Laser Hazard - Skin

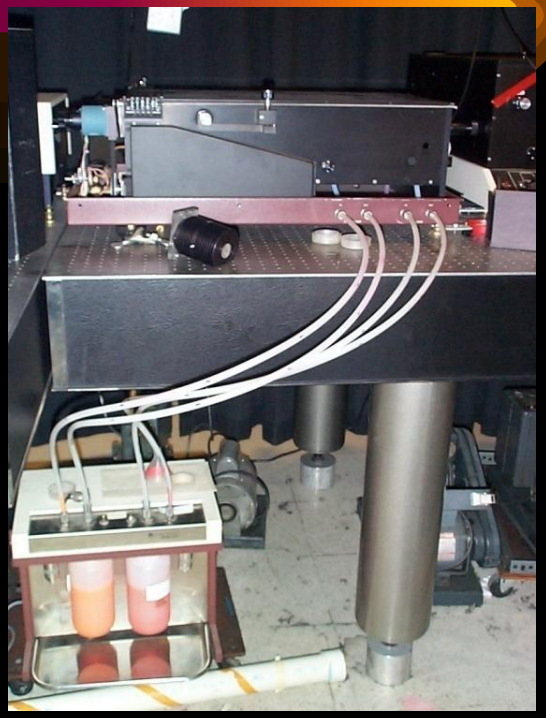
Skin Penetration vs. Wavelength



Laser Hazard - Reaction Materials

- Reactions induced by lasers can release hazardous particulate and gaseous products
  - LGAC – laser generated airborne contaminates
  - Fluorine gas – excimer lasers
  - Ozone – UV lasers
- Ignition of gases or fumes from the laser
- Engineering controls (i.e. ventilation) should be used
- All hazardous materials must be properly used, stored, and controlled to prevent fires

Laser Hazard - Dyes and Solutions



- Dyes vary greatly in toxicity
- Some are flammable
- All dyes must be treated as hazardous chemicals
- Obtain MSDSs for all dyes and solvents (e.g. DMSO)
- Use and store all dyes and solvents in accordance with the University's Chemical Hygiene Plan
- Wear lab coat, eye protection and gloves

Laser Hazard - Electrical Hazards

- Lethal electrical hazards are particularly present when high-power laser systems are used
- Can be a fire hazard
- EH&S offers electrical safety courses, check CU Learn or contact EH&S

Basics for Preventing Electrical Shock

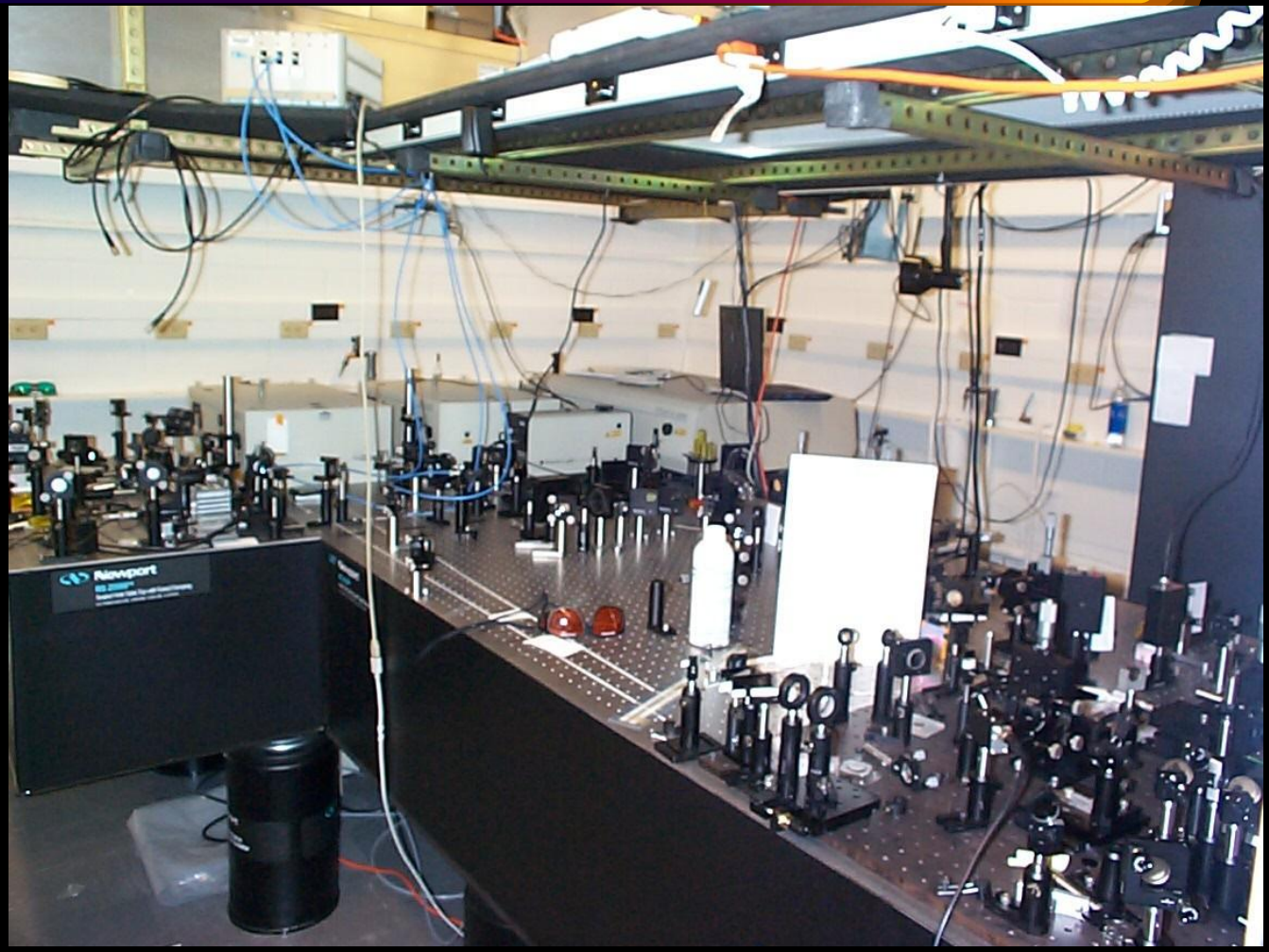
- At least one person should learn CPR rescue procedures
- Avoid wearing rings, metallic watchbands and other metallic objects
- When possible, use only one hand in working on a circuit or control device
- Never handle electrical equipment when hands, feet or body are wet, perspiring, or when standing on wet floor

Preventing Laser Exposures

- Of all ways to prevent exposures to laser beams, housekeeping and lab cleanliness are most important
- Good, organized optical setups minimize the number of potential reflectors
- Let’s look at some examples….

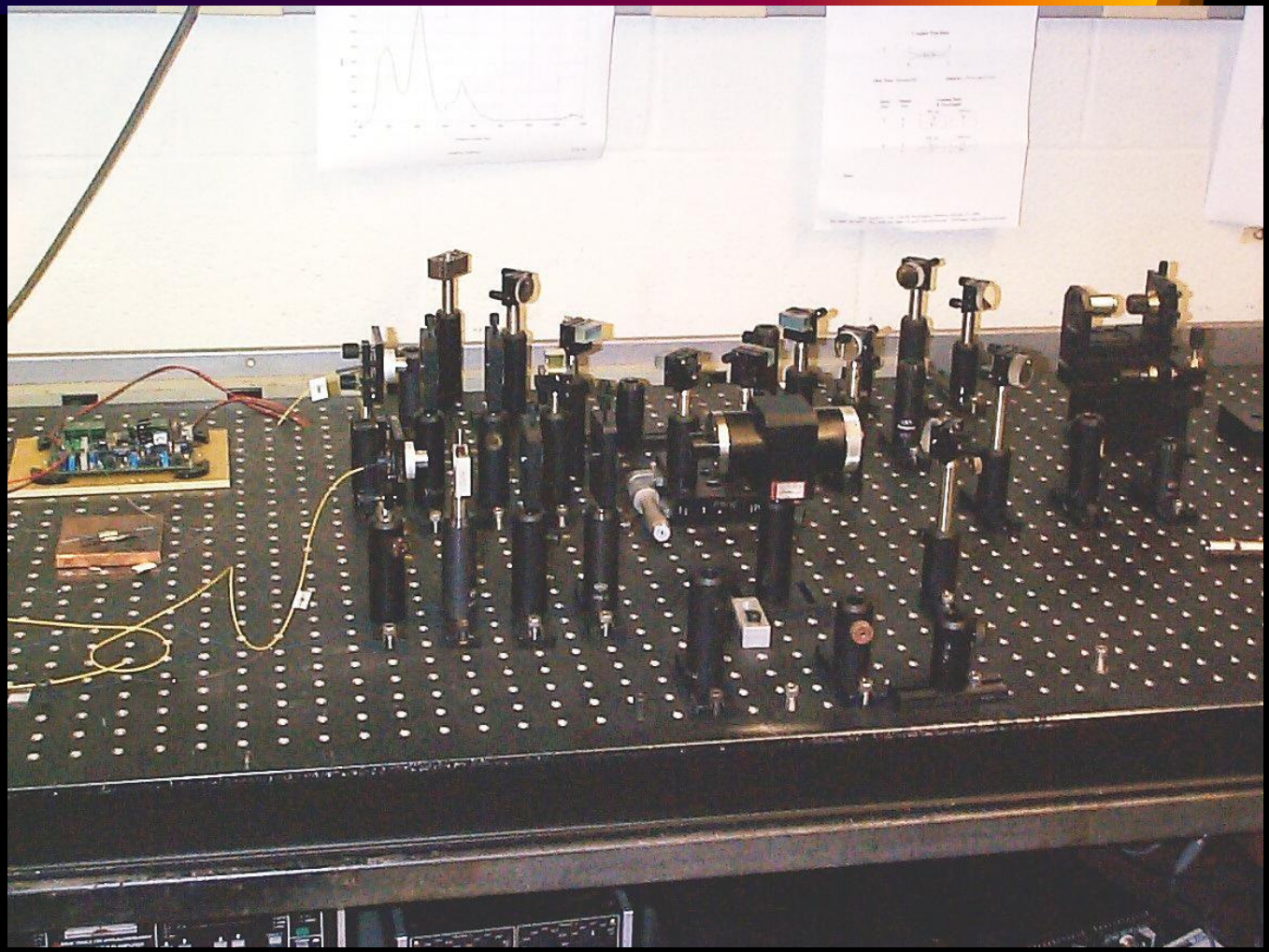
Great Housekeeping

- Well organized, clean
- Only necessary items on table top
- Beam stops in use



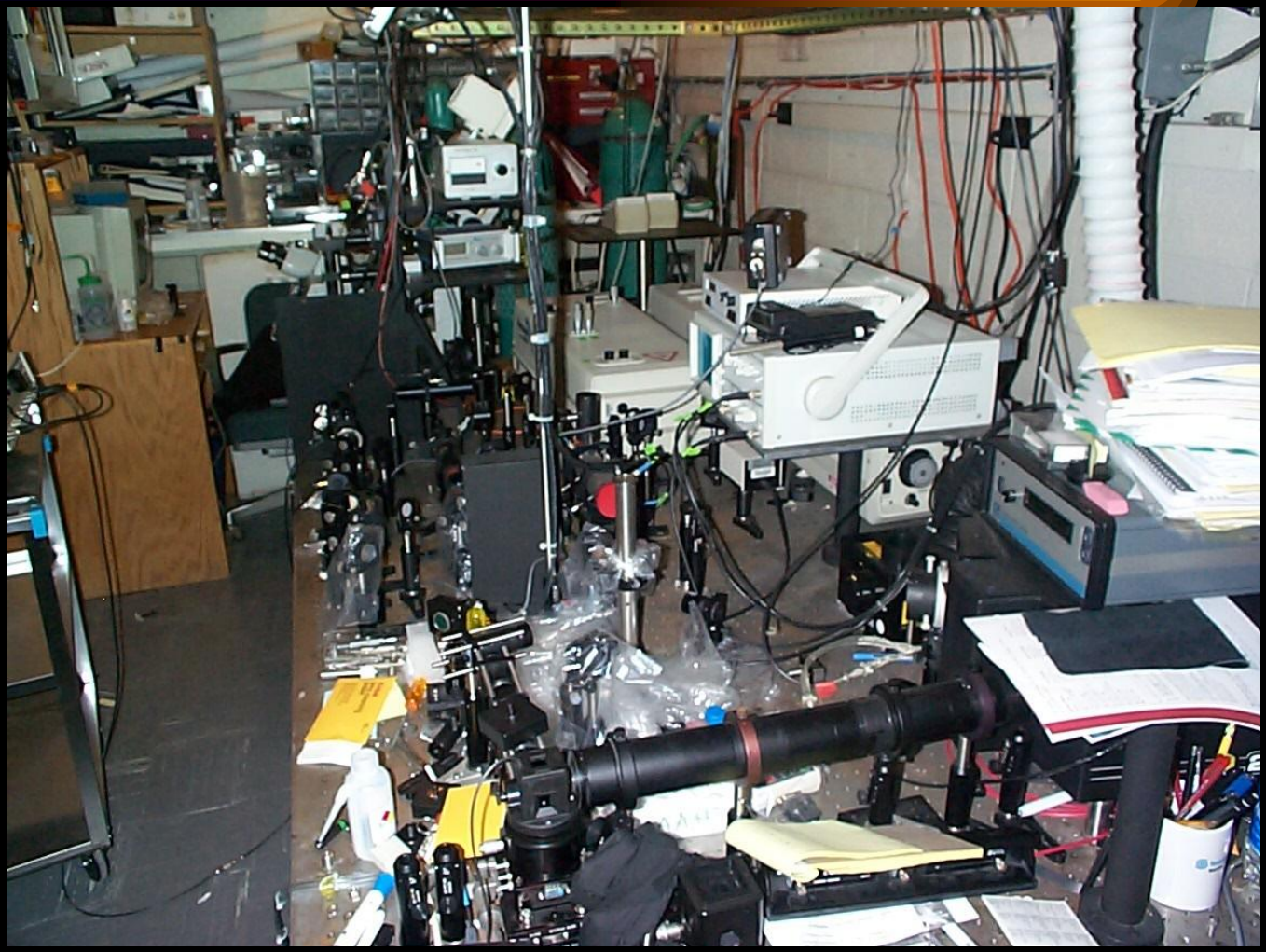
Great Housekeeping

- Note fiber optics – use them whenever possible to enclose beam



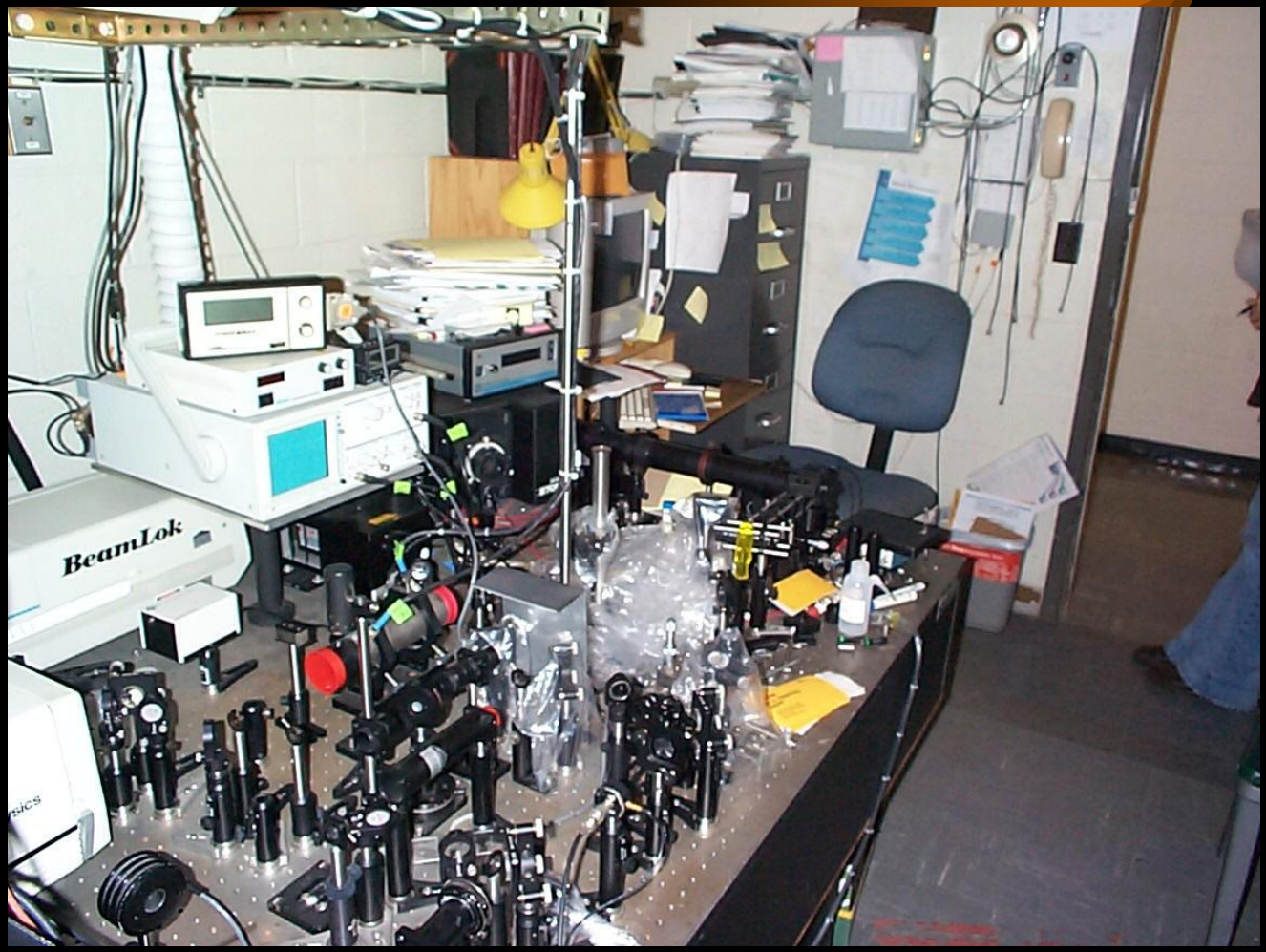
Poor Housekeeping

- Too many uncontrolled reflecting surfaces



Poor Housekeeping

- Another view of previous lab
- Unprotected doorway is not allowed (see Cornell Laser Safety Manual)



Overview of Safety Requirements for Class 3b and 4 lasers

- Low hazard lasers (Class 1, 2, 2a, and 3a) require minimal safety control measures
  - Laser use areas require posting a sign (Class 2, 2a, 3a)
  - Eye protection is recommended (Class 2, 2a, 3a)
  - See the Cornell Laser Safety Manual
- If you use only low hazard lasers, you are done with this class, click *HERE* to skip to the final slides
- Class 3b and 4 laser users need to continue to the next slides

Overview of Safety Requirements for Class 3b and 4 lasers

Topics

- Registration with EH&S
- Alignment guidelines
- Access restrictions and safety control measures
- Posting and labeling
- Medical monitoring
- Protective eye wear and clothing

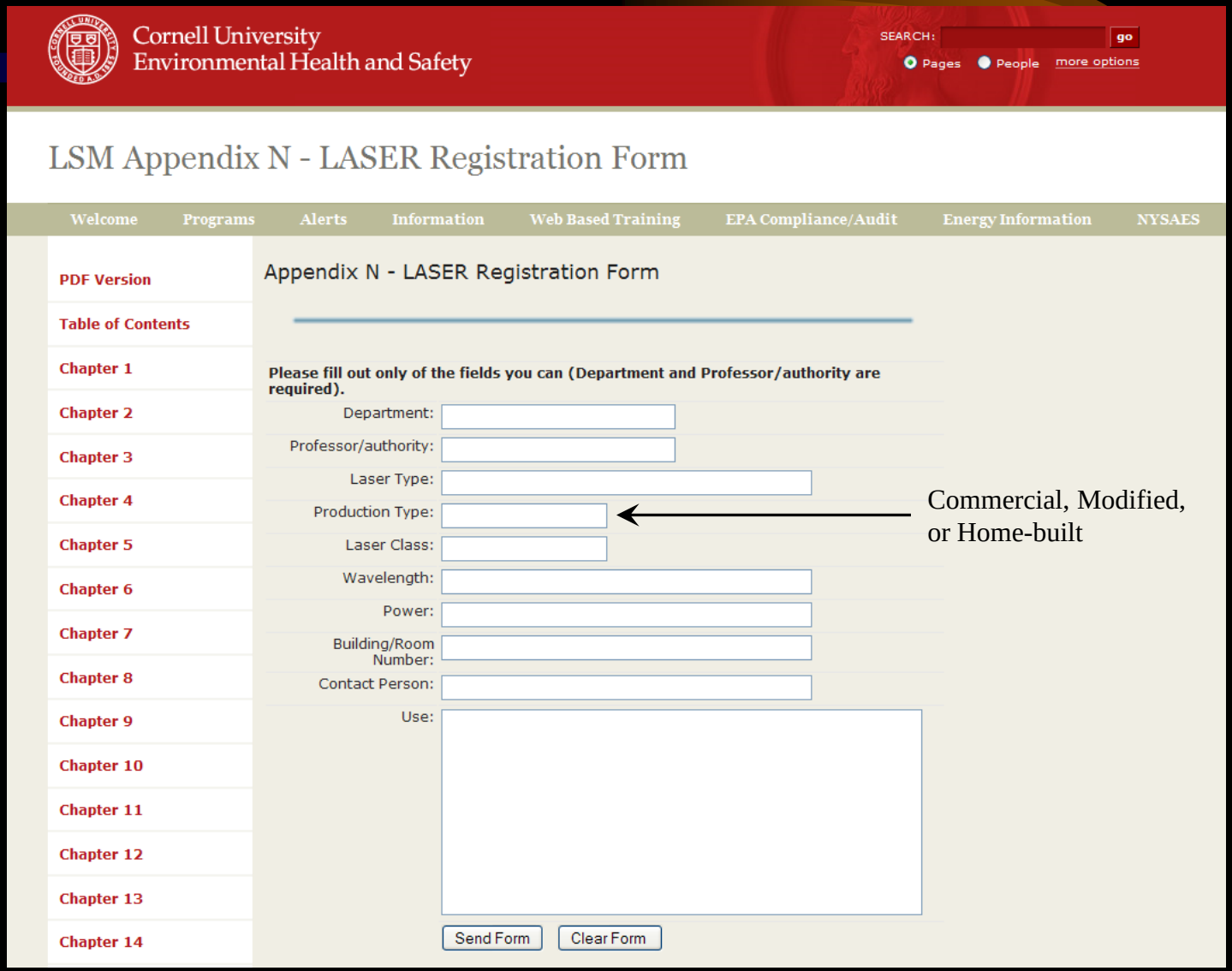
Overview of Safety Requirements for Class 3b and 4 lasers

Registration with EH&S

- Required for campus inventory
- On-line submission or print PDF for new lasers
- Available from EH&S Radiation Safety web page
  - *www.sp.ehs.cornell.edu*
  - Click link for *Lab & Research Safety* followed by *Radiation Safety*
  - Click link for *Class 3b and 4 Laser Registration Form*
  - Example in next slide

Overview of Safety Requirements for Class 3b and 4 lasers

On-line Laser Registration Form



Safe Beam Alignment

- Most beam injuries occur during alignment
- Only trained (complete this class and receive in-lab hands-on instruction) personnel may align class 3b or class 4 lasers *(NO EXCEPTIONS!)*
- Laser safety eyewear is *required* for class 3b and class 4 beam alignment
- ANSI *requires* approved, written alignment procedures for *all* Class 3b and Class 4 alignment activities

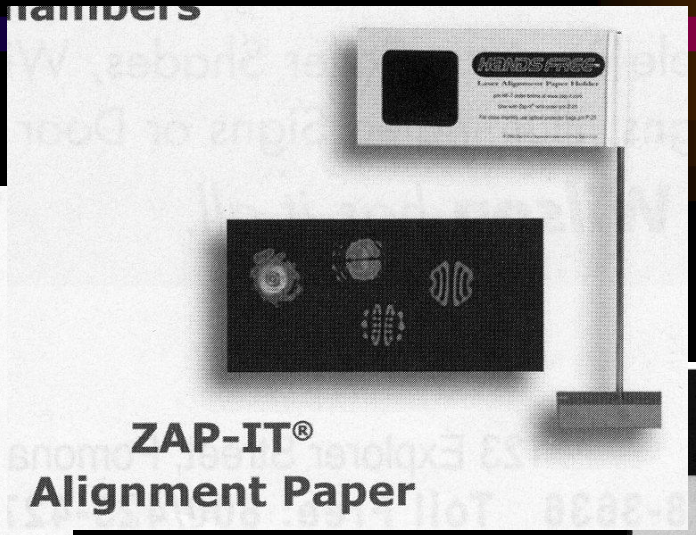
Alignment Guidelines for Class 3b and 4 Lasers

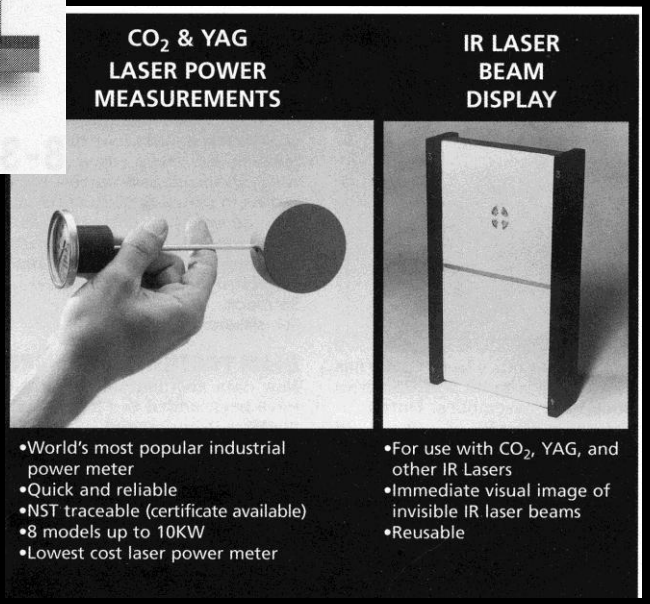
- Exclude unnecessary personnel from the laser area during alignment
- Where possible, use low-power visible lasers coaxially with high power beam path
- Perform alignment tasks using high-power lasers at the lowest possible power level
- Keep beam paths above or below eye level

Alignment Guidelines for Class 3b and 4 Lasers

- For invisible beams
  - Use beam display devices
  - Image converter viewers e.g. IR cameras
  - Phosphor cards
  - Examples – next slide

Alignment Guidelines for Class 3b and 4 Lasers





Alignment Guidelines for Class 3b and 4 Lasers

- Use beam stops, protective barriers, etc. to
  - Prevent beams entering areas with uninvolved personnel
  - Prevent overshooting optics during alignment
  - Block all stray reflections
- Post temporary signs at all laser use area entrances during alignment

Safety Controls - Access Restriction

- All entrances to the laser use area (i.e. NHZ) are to be protected so a stray beam cannot escape and eye protection can be put on *before* entering the area

- Entryway protection can be laser barrier screen or curtain
- Movable curtains are to be interlocked to the laser, fixed curtains do not normally require interlocks

- Look for “one bounce” pathways to unprotected areas – shield or block pathways that allow a beam to escape after one reflection

Safety Controls - Operating Procedures

Class 4 lasers are *required* to have written operating procedures – recommended for Class 3b

Procedures need to address:

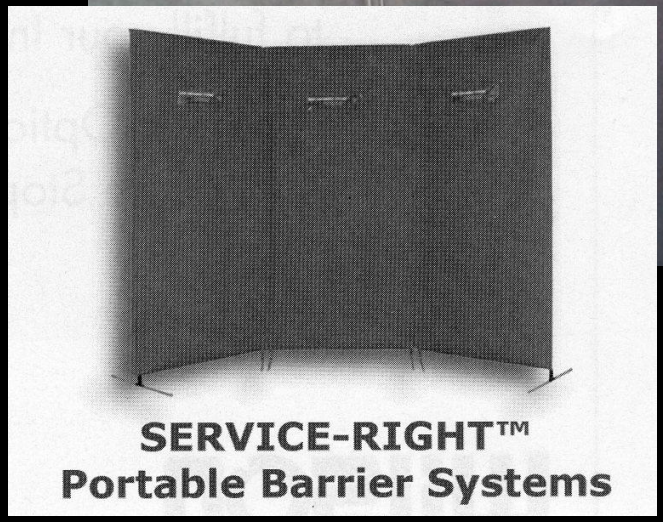
- Start-up process
- Special procedures for performing laser work
- Shutdown procedures
- Special hazards or actions required
- Any other information important to the safe use of the laser

Operating Procedures – Continued

- Maintenance/services procedures
- Hazards Summary (beam, non-beam)
- The nominal hazard zone (NHZ) for the above procedures
- Required control measures (access controls, system controls, personnel controls, emergency instructions)
- Protective eye wear and other personal protective equipment

Laser Safety Curtains

- Made of laser resistant material
- Interlocked if appropriate, see Laser Safety Manual
- Use portable stands for flexibility
- EH&S can provide supplier info and curtain recommendations



Ventilation

- F or Cl excimers
- O_3 from UV beams in air, use N_2 fill
- LGAC – mostly unknown composition, treat as hazardous

Emergency OFF Switch

- Emergency OFF button required for Class 4
- Locate at door and where ever needed
- Recommended for high power Class 3b
- All 3b and 4 lasers have capability built-in for remote shutdown
- Alternate is shutter at laser

Laser Safety Signs and Labels

- Class 4 lasers require lighted sign
- Switch for light to be located near laser controls
- Turn ON when laser is operating and turn OFF when laser is off.

- Warning sign required at entrance to laser use area NHZ
- EH&S can provide paper signs for your specific lasers

Laser Safety Signs and Labels

Sign to indicate periods of increased risk

- Laser alignment and/or maintenance at entrance to high hazard area

Video – Laser Safety in Labs

Click video to play

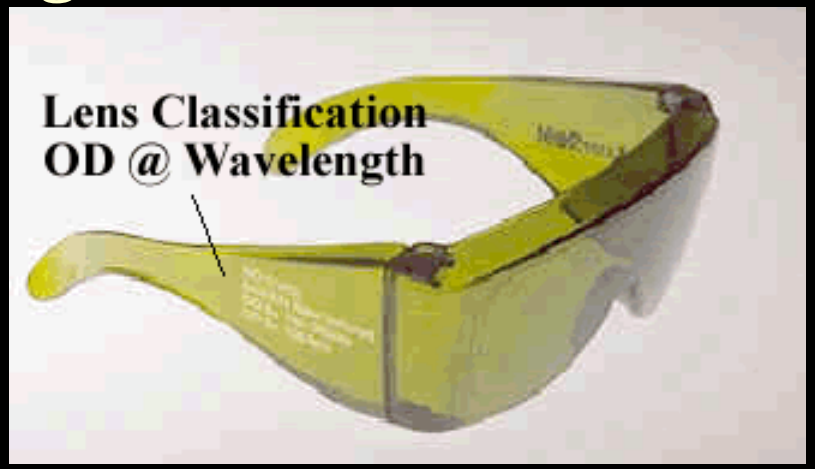
10m 4s

Medical Monitoring

- Required for Class 3b and Class 4 laser users
- Completed *prior* to using lasers
- Provides a baseline condition of your eyes
- Contact Gannett Health Center Occupational Medicine office at 255-6960 to set up an exam

Personal Protective Equipment (PPE)

- Appropriate eyewear
  - Eyewear must be for the appropriate laser wavelength, attenuate the beam to safe levels, yet be comfortable enough to wear
- Gloves – UV
- Lab coats and skin covering – UV

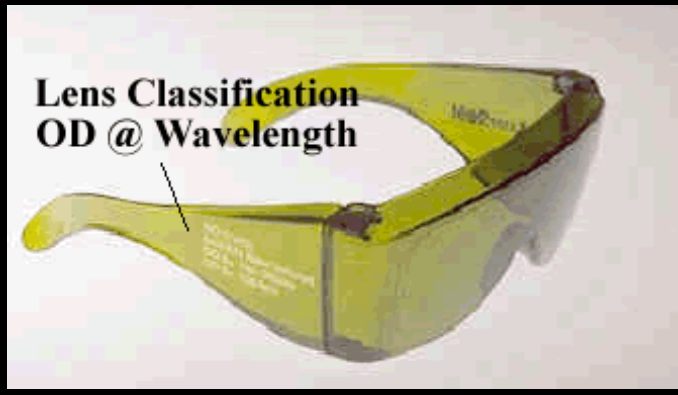


Personal Protective Equipment (PPE)

- How Do I Pick the Right Eye Protection?
  - For the laser find
    - Wavelength (nm)
    - Energy (J/cm^2) and pulse rep rate for pulsed lasers or
    - Power (mW/cm^2) for continuous wave lasers
  - Look up MPE based on wavelength and maximum expected exposure time (i.e. ANSI Z136.1)
    - Time depends on working conditions e.g. brief “flash” exposure to long term observation of diffuse reflection – be conservative
  - OD = $\log_{10}$ (laser output / MPE)

Personal Protective Equipment (PPE)

- Example for Calculating OD
  - Assume HeNe laser at 638 nm, 20 mW output, maximum of 3 sec exposure and 2 mm beam diameter
  - ANSI Z136.1 gives MPE = $1.8\ t^{0.75} \times 10^{-3}$ J/cm2
  - MPE = $\underline{4\ mJ/cm^2}$
  - Laser = 60 mJ (using J = W x sec)
  - Beam smaller than eye pupil so use pupil area = 0.38 cm^2
  - Laser = 60 / 0.38 = $\underline{158\ mJ/cm^2}$ (avg over eye entrance area)
  - OD = $\log_{10}$ (158 / 4) = 1.6 round up to 2
  - Use eye protection with an OD of ≥ 2
  - You will still see the beam with this OD



Resources and Information

- Cornell Laser Safety Manual
  - See the *Lab & Research Safety* followed by *Radiation Safety* web page link at *www.sp.ehs.cornell.edu*
- Laser Institute of America
  - *www.laserinstitute.org*
  - LIA guide for the selection of laser eye protection
- FDA CDRH Federal regulations
  - *www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfcfr/CFRSearch.cfm?FR=1040.10*
- Laser Tutorials
  - *http://www.repairfaq.org/sam/lasersam.htm* - technical tutorial, lots of links to other pages too
  - Google *LASER SAFETY*
- ACGIH
  - *www.acgih.org*
- OSHA
  - *http://www.osha.gov/SLTC/laserhazards/*

Questions?

Thank You!

Contact:
Environmental
Health & Safety
255-8200